RS Spectral Radiative Kernel And Fingerprinting For CLARREO

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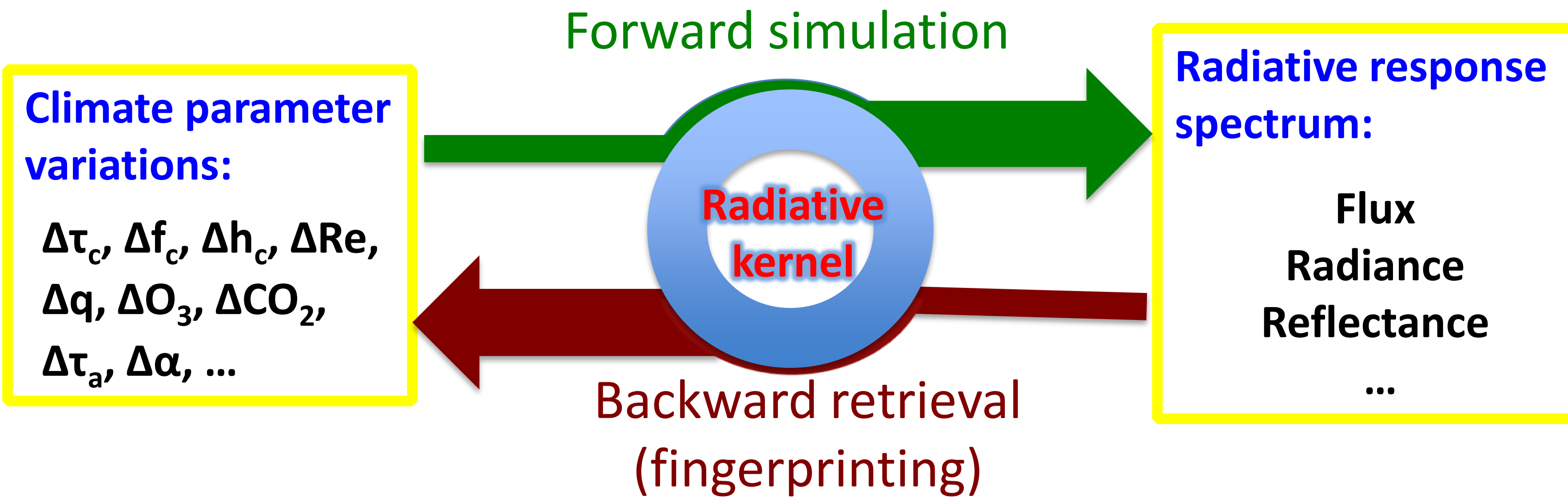


Radiative kernels relate the differential radiative response to the climate parameter variations between two climate states.

Modeling and retrieving based on radiative kernel approach are different from the usual RT modeling and remote sensing retrieval in that

- **It is not for the absolute parameter values but for their variations between two mean states.**
- **It is for average quantities over large spatial/temporal scales instead of local or instantaneous values.**
- **The variations in both the parameters and radiation must be small compared to their means.**

CLARREO benchmark measurements concern the mean spectrum in large climate domains instead of instantaneous spectrum; the kernel approach is suitable for analyzing CLARREO data.

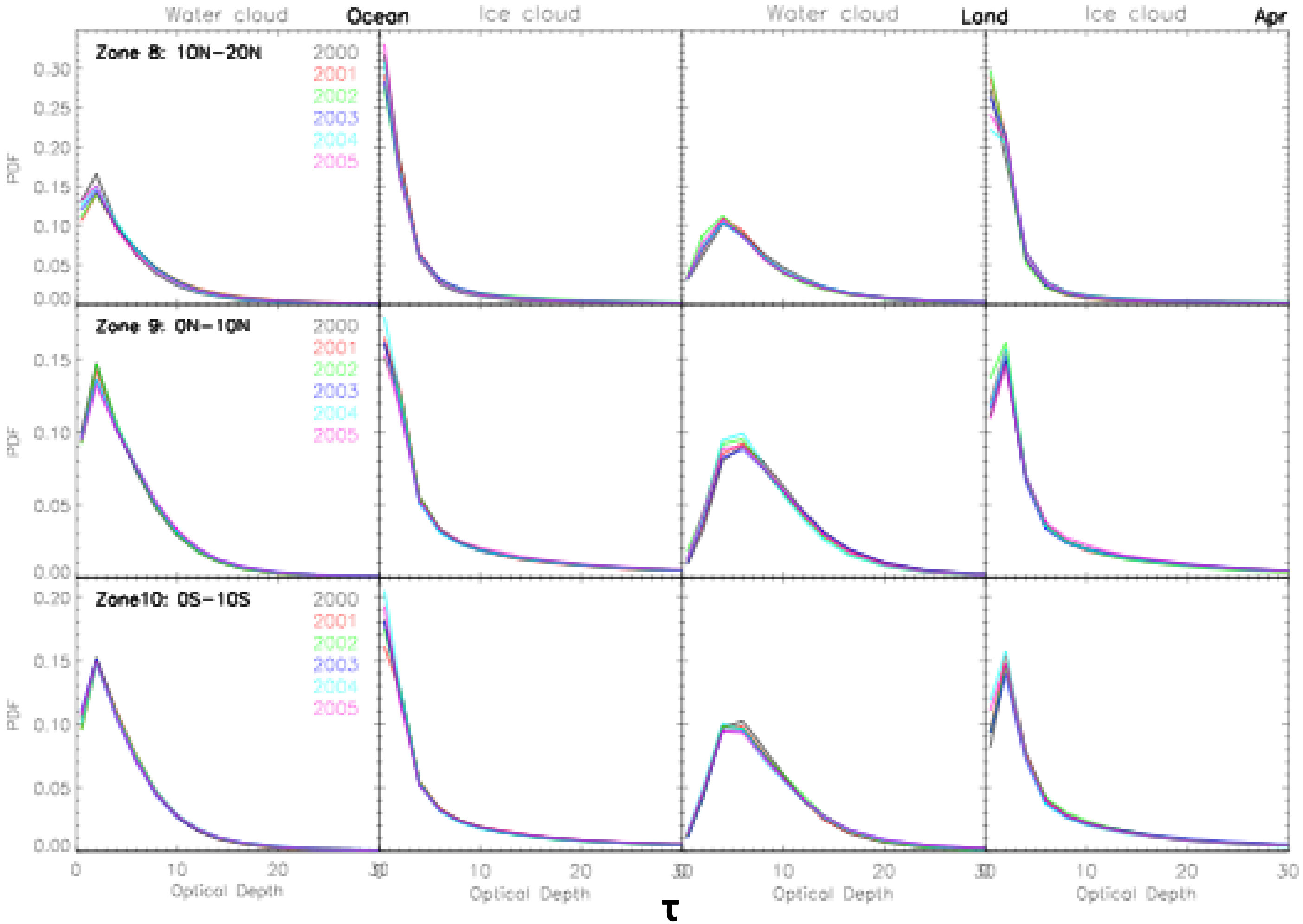
Using CERES/MODIS/GEOS data and SMOBA ozone, we have constructed the basic kernels for monthly zonal (10-deg) mean climate parameters:

Atmospheric properties: PW, AOD, O_3.

Surface properties: Snow coverage, Seaice concentration, etc..

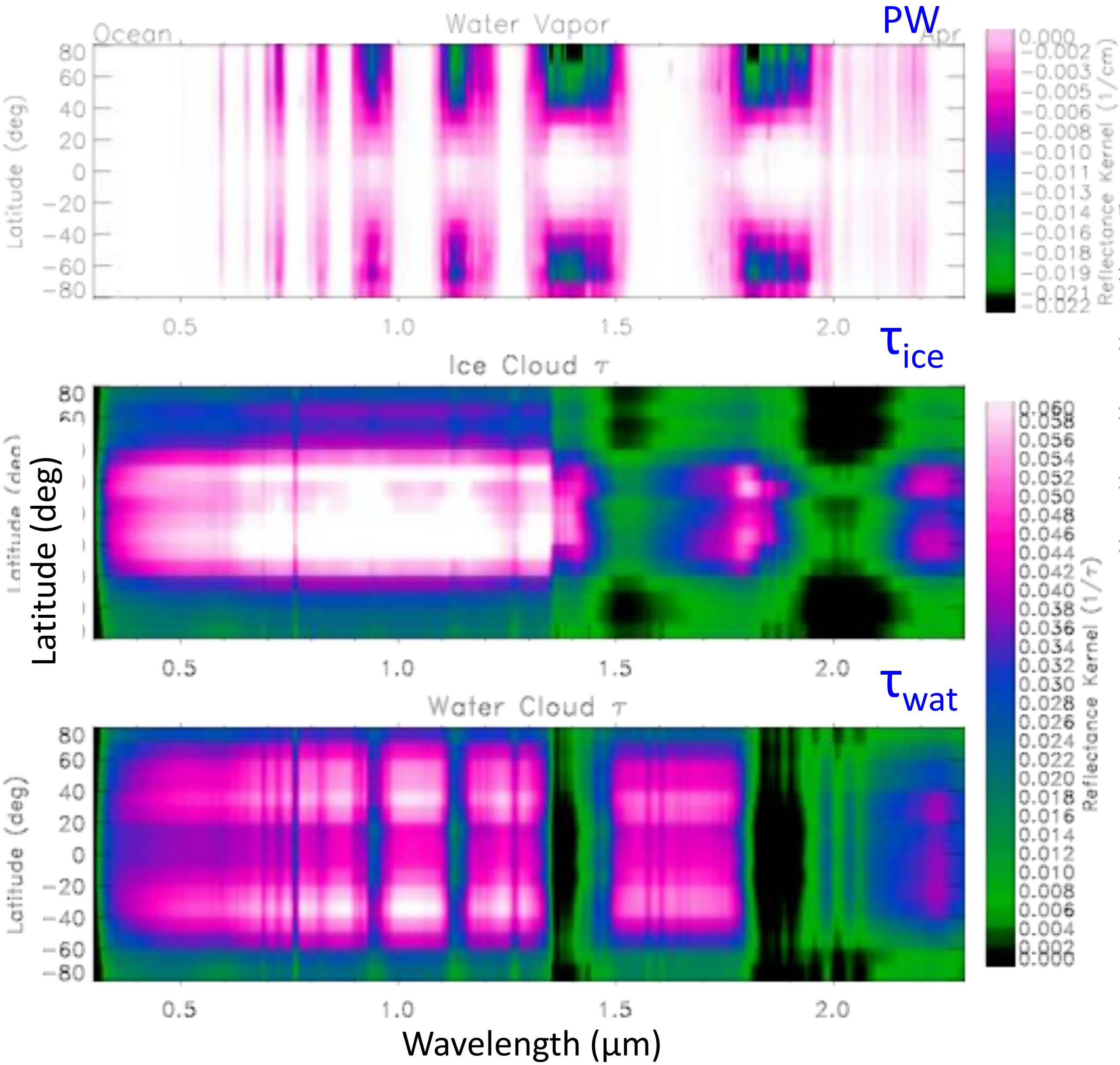
Cloud properties: τ, f_c, h, D_e, R_e.

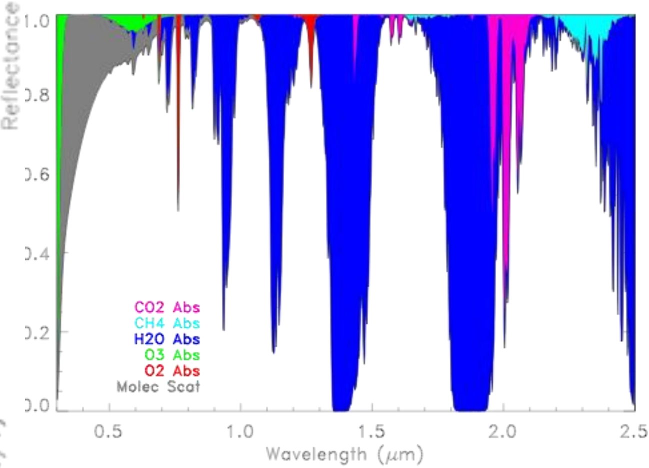
MODIS clouds in CERES SSF data are used to derive the probability distribution function (PDF) of cloud τ in each month to account the large cloud variation from footprint to footprint.



Example of cloud PDF

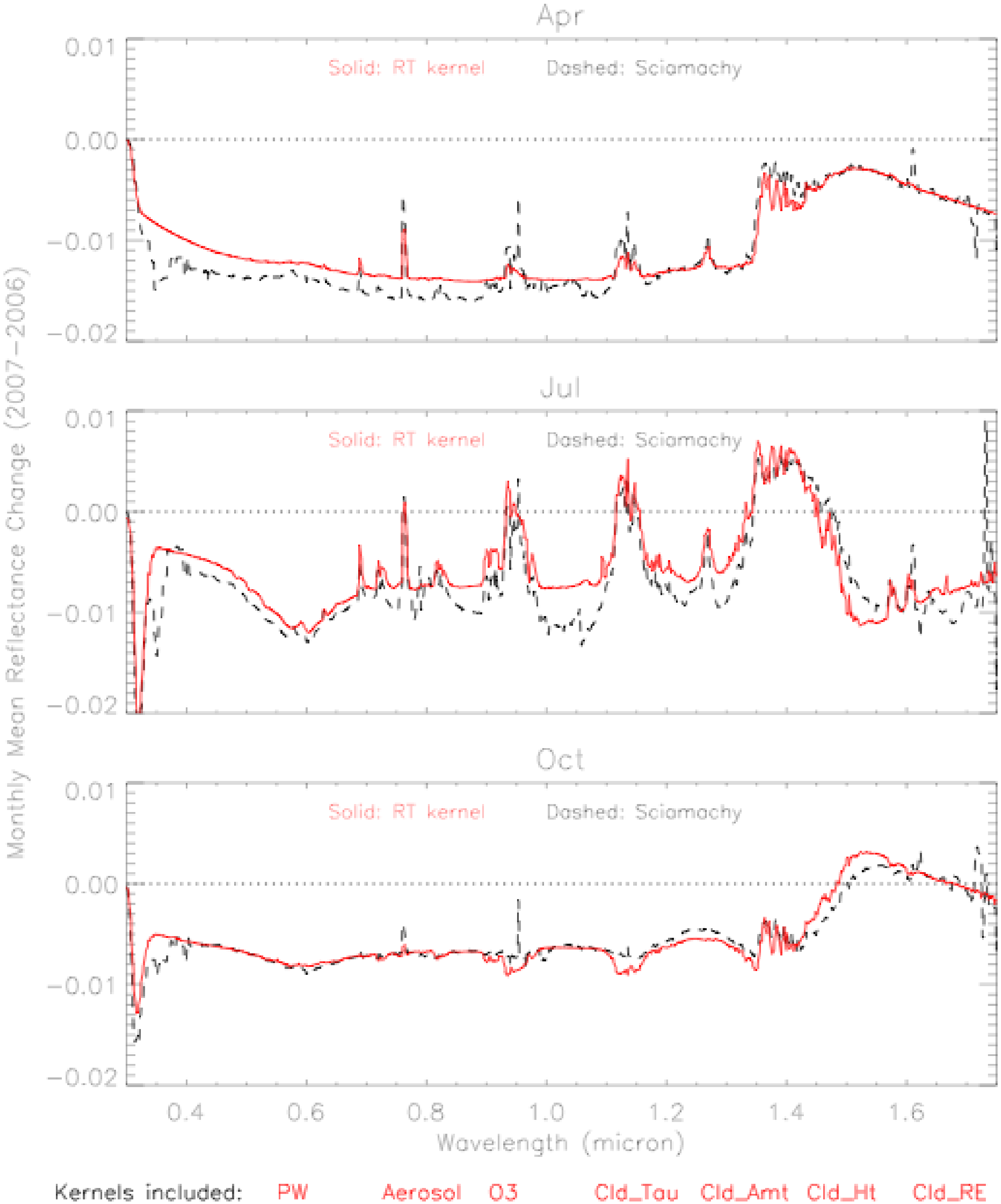
The PDF of cloud τ measured by MODIS in three 10 degree zones (20N-10S) in April months spanning 2000-2005, separated by cloud phase and by ocean and land areas.





Total column integrated atmospheric transmission and absorption by atmospheric molecules. Different colored areas represent absorption by major absorptive gases.

An example of solar spectral reflectance kernel. This example is for the monthly mean reflectance over ocean in April.

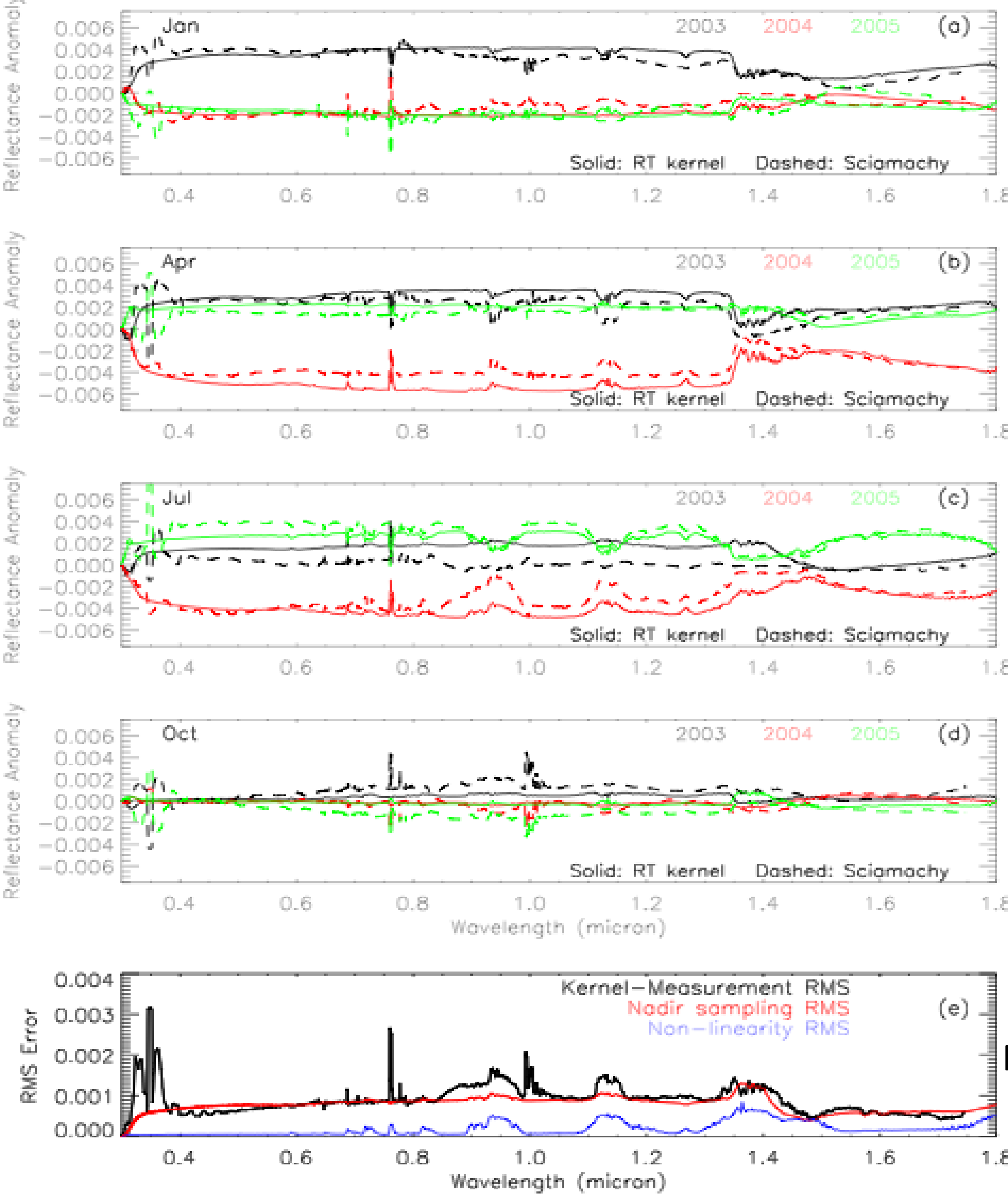


The radiative kernel approach provides a simple way to separate the total radiative response or interannual variation to different dependent parameters.

An example of radiative attribution.

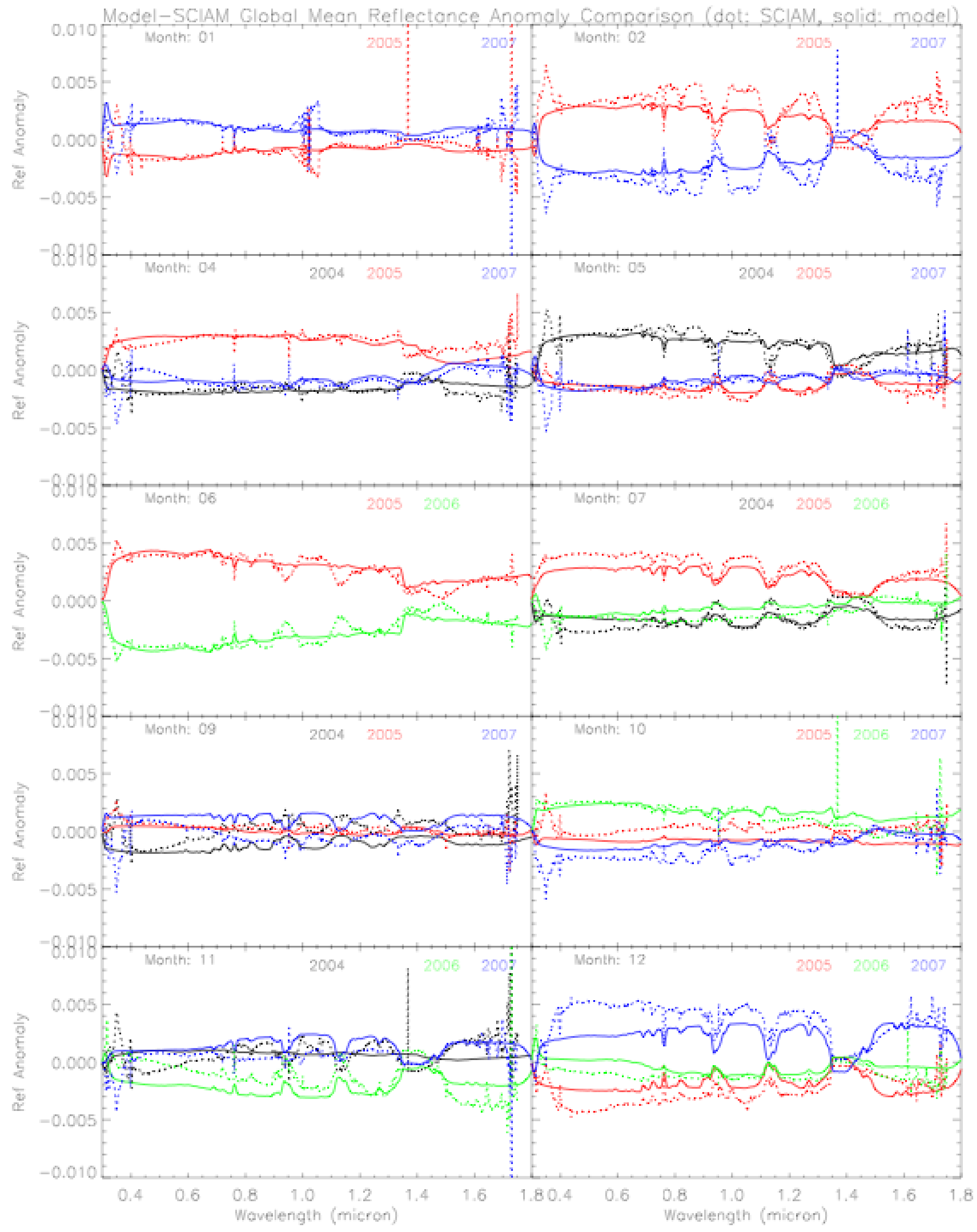
Kernels applied:

PW, AOD, O_3
+ Cloud τ
+ Cloud amount
+ Cloud height
+ Cloud particle size



Comparison of monthly global mean reflectance anomalies using kernel approach with SCIAMACHY observations over ocean in four months.

RMS



Model-observation comparison of monthly global mean reflectance anomalies using new SCIAMACHY data.

(Results here are preliminary, SCIAM data are not complete.)

Using Kernels For Backward Retrieval: Fingerprinting

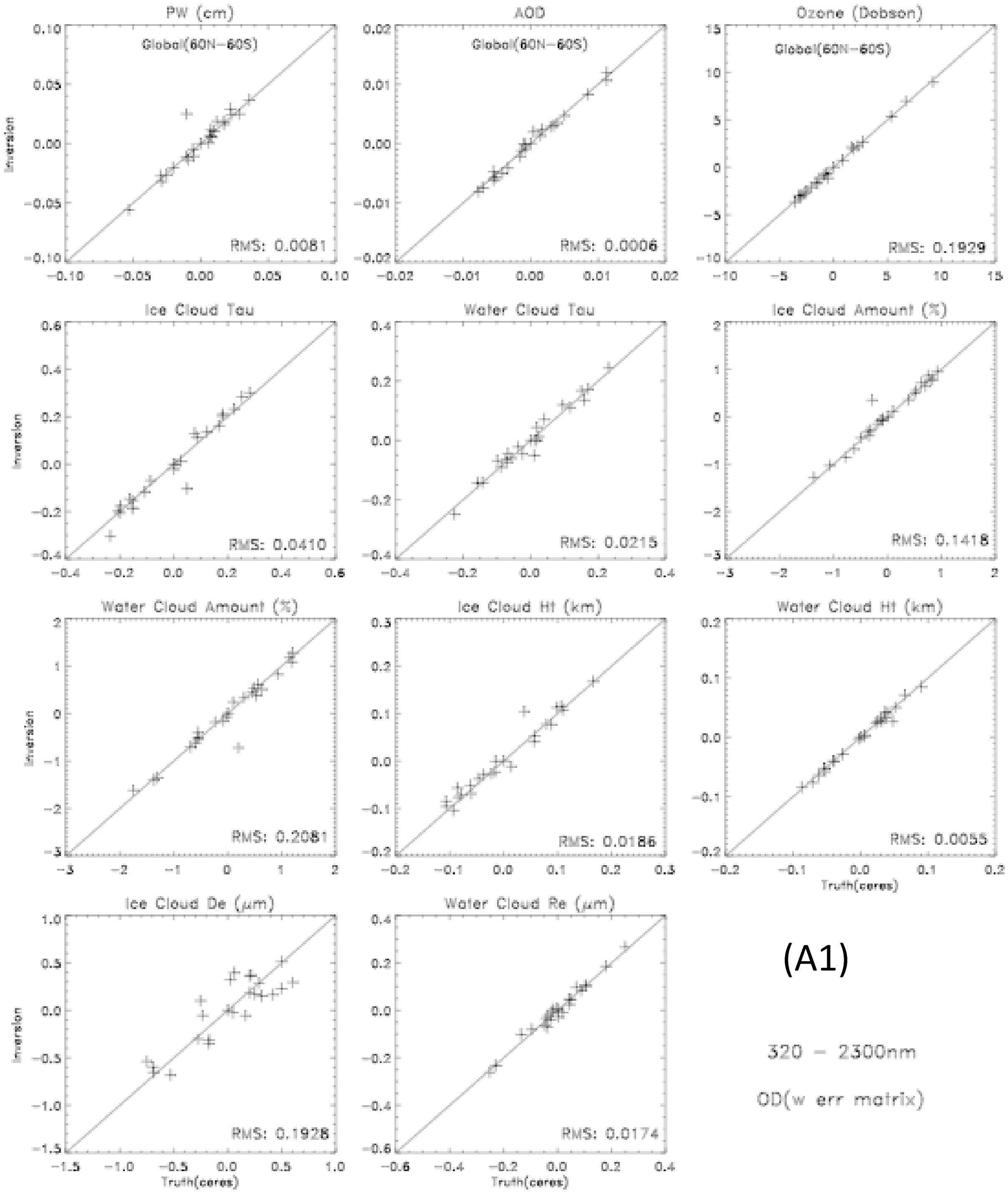
$$\Delta R = K \Delta a + e$$

$$[\Delta R]_{nw \times 1} = [K]_{nw \times nx} [\Delta a]_{1 \times nx} + [e]_{nw \times 1}$$

ΔR Reflectance change spectrum
K Kernel matrix (fingerprints)
Δa To be retrieved parameter changes corresponding to Δ***R***
e Errors or residuals that cannot be explained by fingerprints

There are different approaches for the fingerprinting:

- ✧ Optimal detection
- ✧ Constrained linear inversion
- ✧ Linear regression
- ✧ …



(A1)

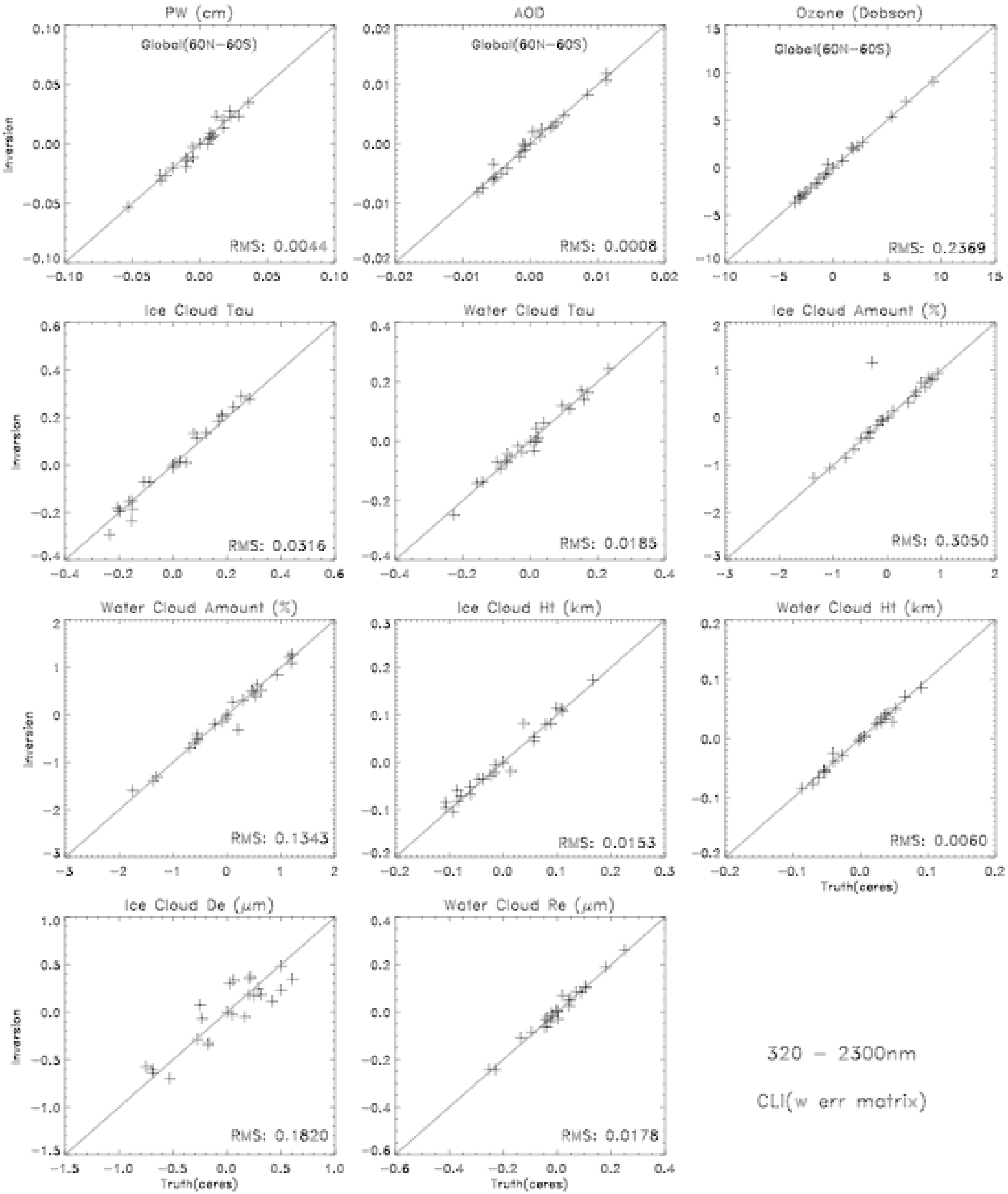
Experiment A1:

Global mean parameters retrieved by optimal detection and comparison with truth.

Data for 4 months 6 years (2000-2005).

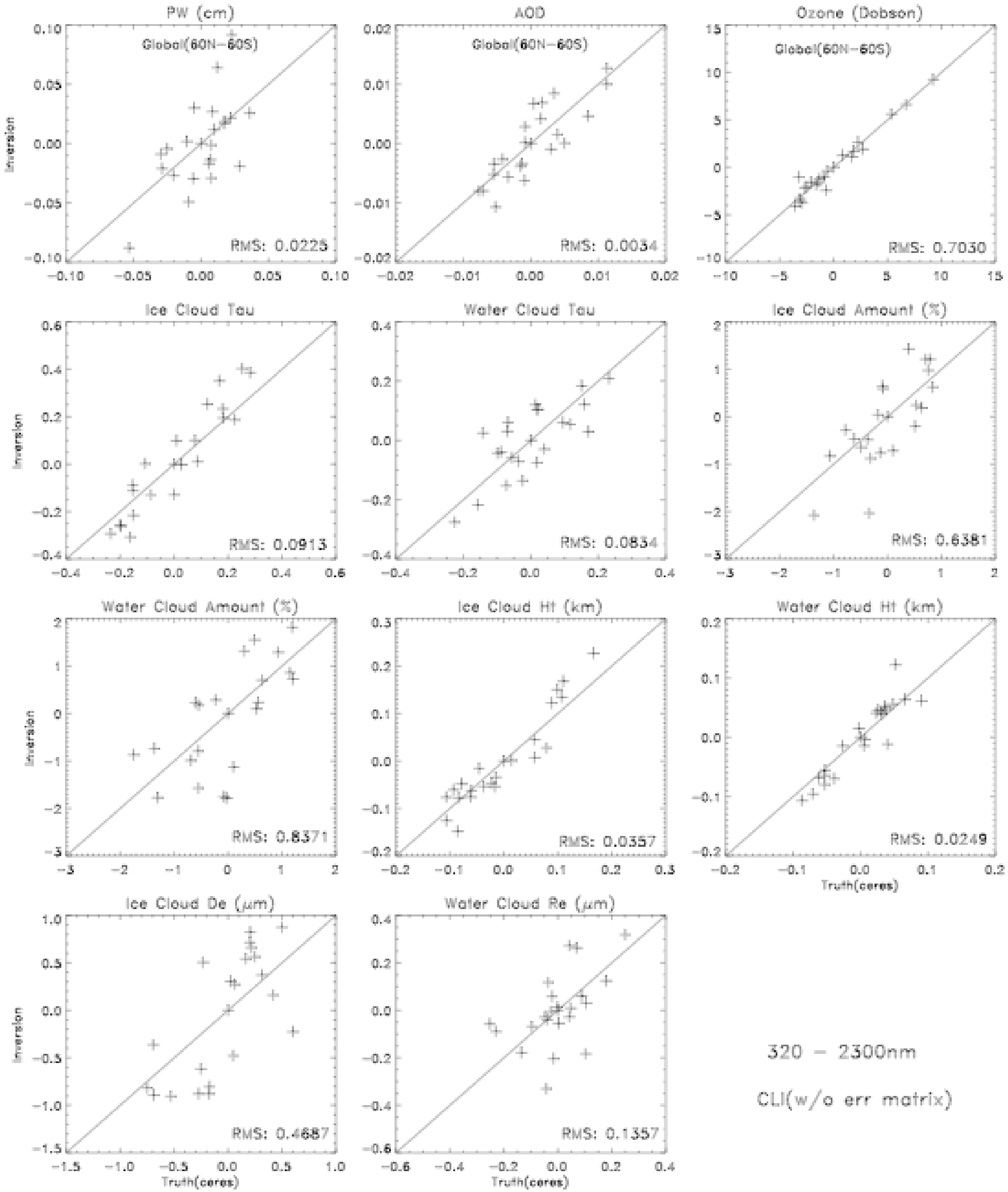
Kernels are averaged over global.

(Idealized case)



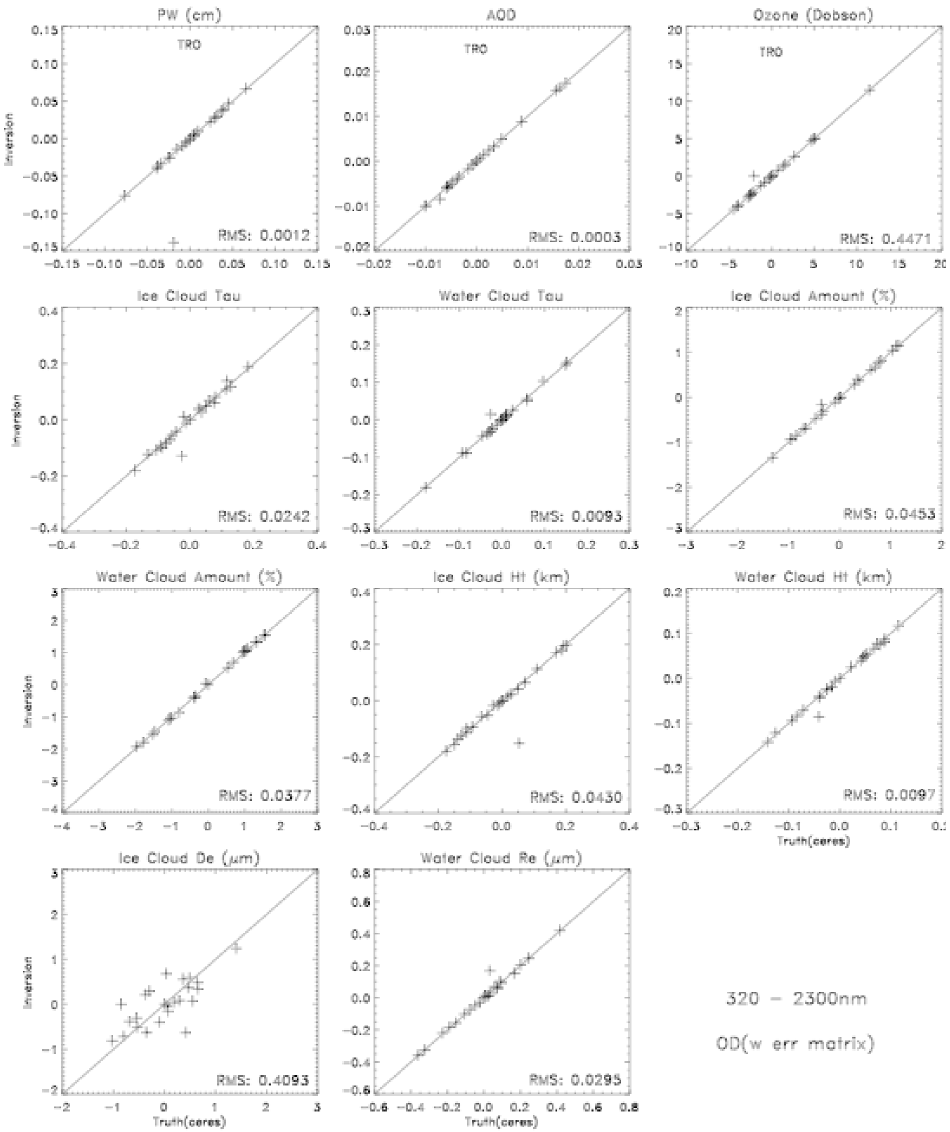
Experiment A2:

Same as A1, but use the constrained linear inversion. (Err accounted, idealized case).

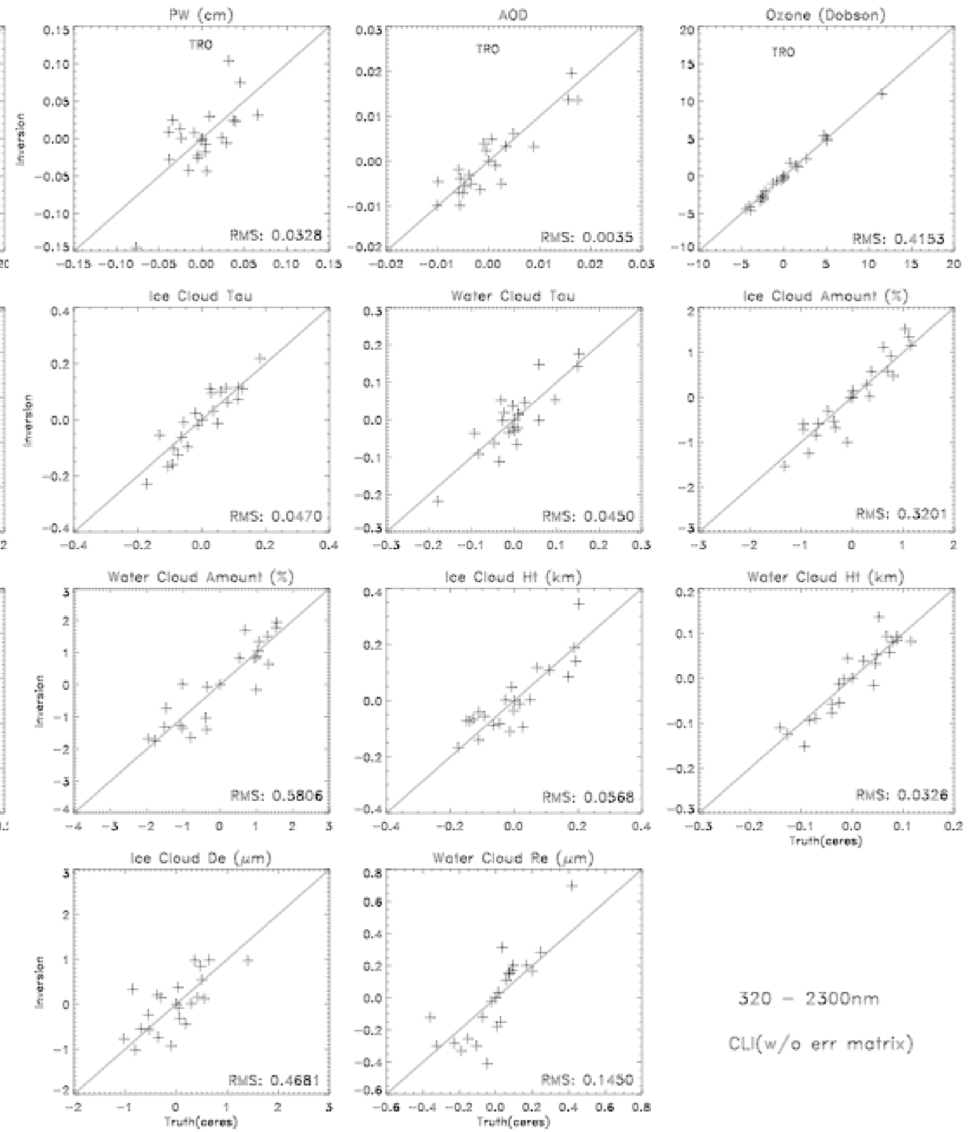


Experiment A3:

Same as A2, but errors are not accounted in the inversion.



Results from optimal detection for the Tropic region (30N-30S). (Err accounted)



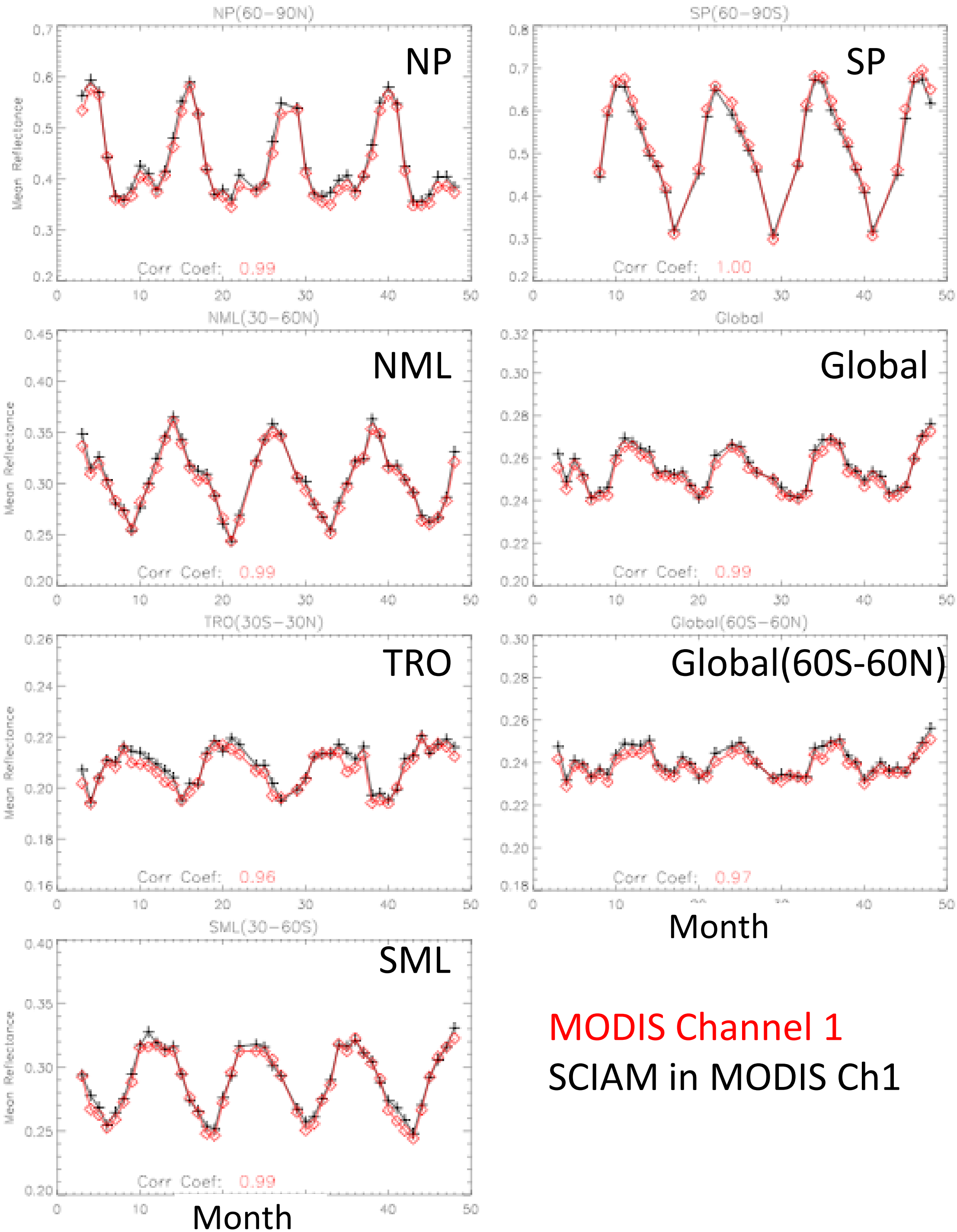
Results from constrained linear inversion for the Tropic region. (Err in data)

Testing Fingerprinting With Kernel Over Real Data

The fingerprinting approach has been proved to work on model simulated data (works on paper). Does it work for real data?

The average time difference of overpass between SCIAMACHY on Envisat (~10:00 LST) and the CERES-MODIS package on Terra (~10:30 LST) is about 30 minutes. Now we have years of SCIAM and MODIS data.

If the mean reflectances measured from the two platforms are well correlated, the atmospheric/cloud properties from MODIS can be used to test and validate the fingerprinting results from SCIAM data.



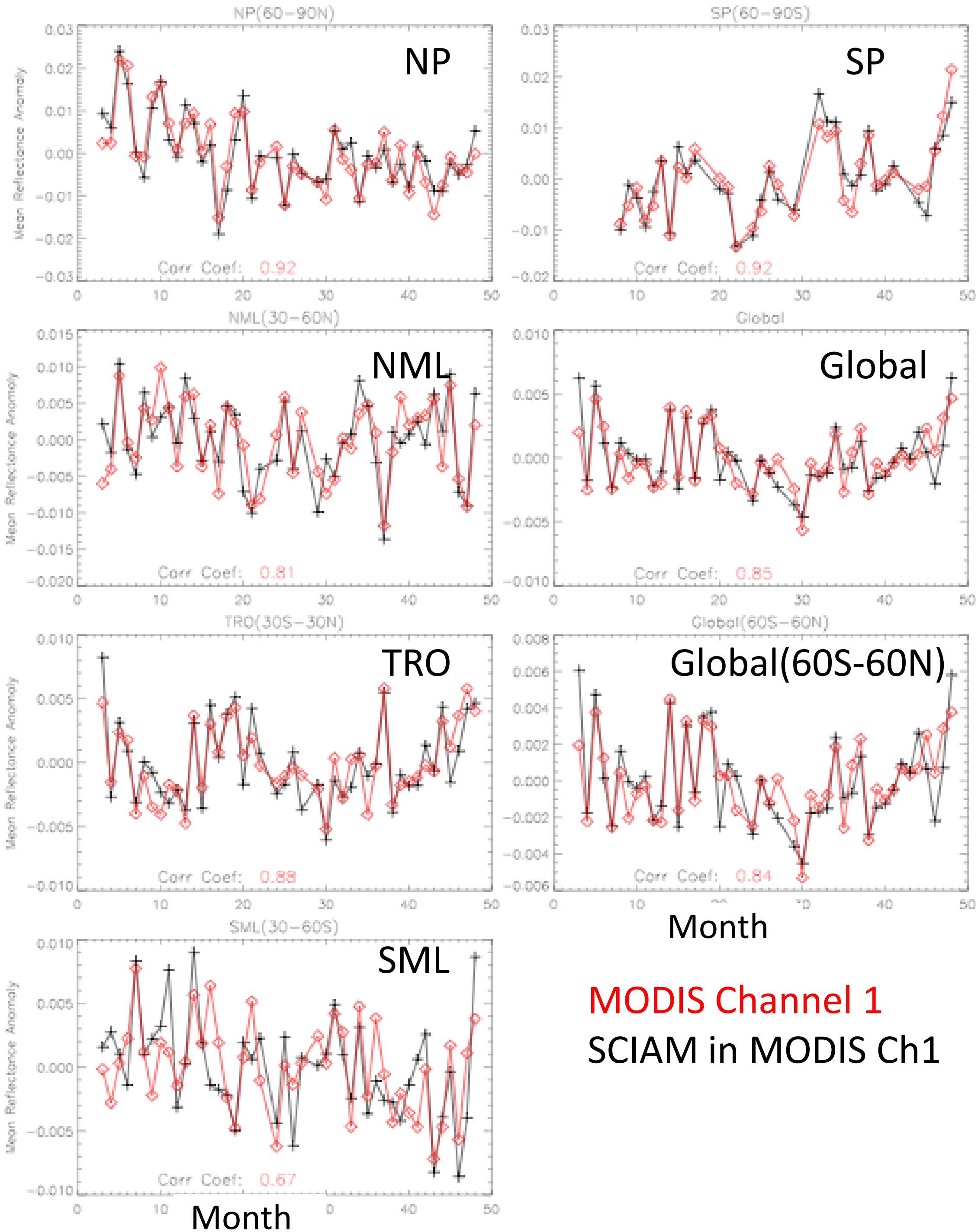
MODIS Channel 1

SCIAM in MODIS Ch1

Comparison of monthly mean nadir reflectance between SCIAM and MODIS (Channel 1) in 5 latitude regions and globe.

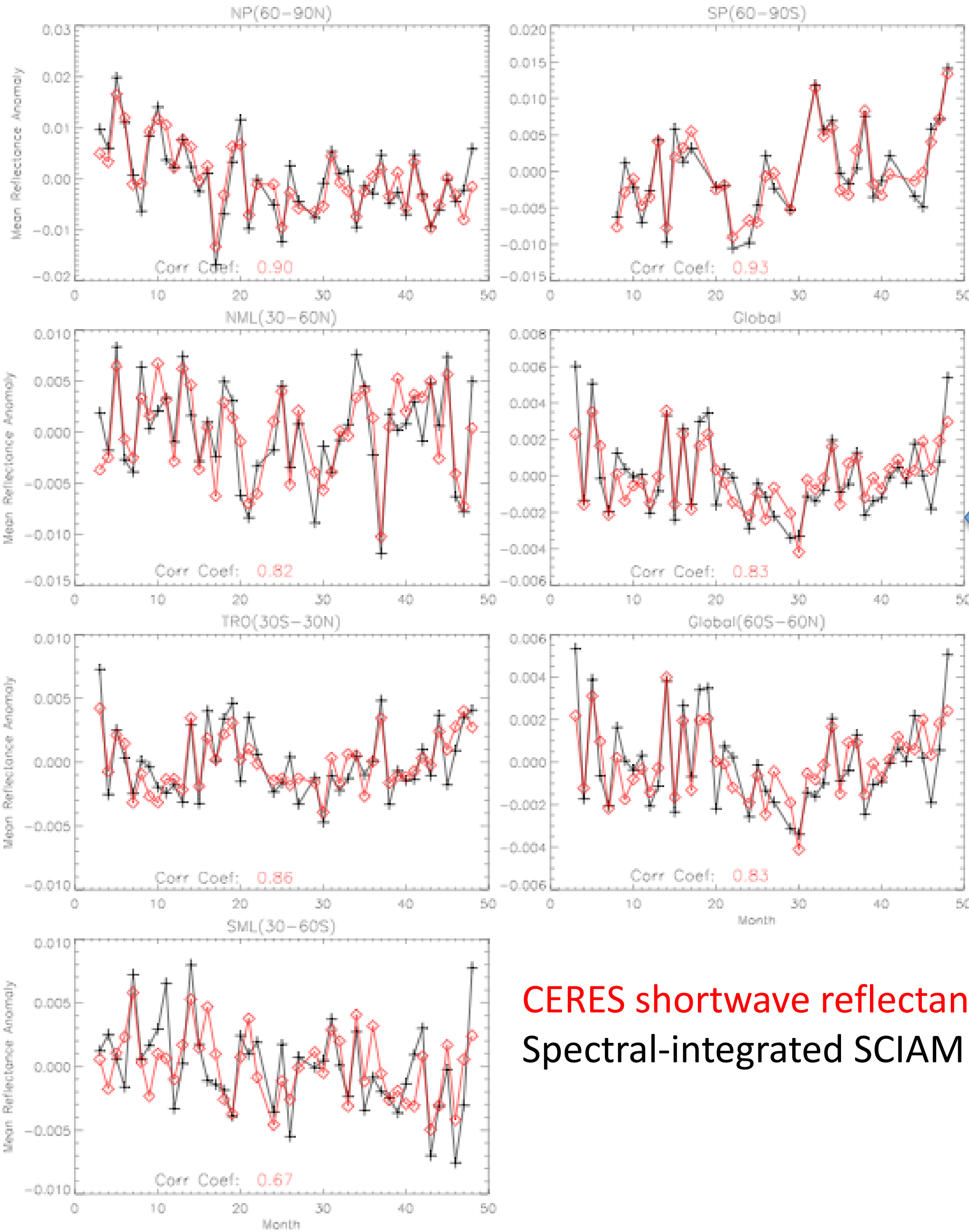
When averaged to large domains, the two measurements are almost the same though they are not co-located at all!

(Results here are preliminary, SCIAM data are not complete.)



Their deseasonalized monthly anomalies are well correlated!

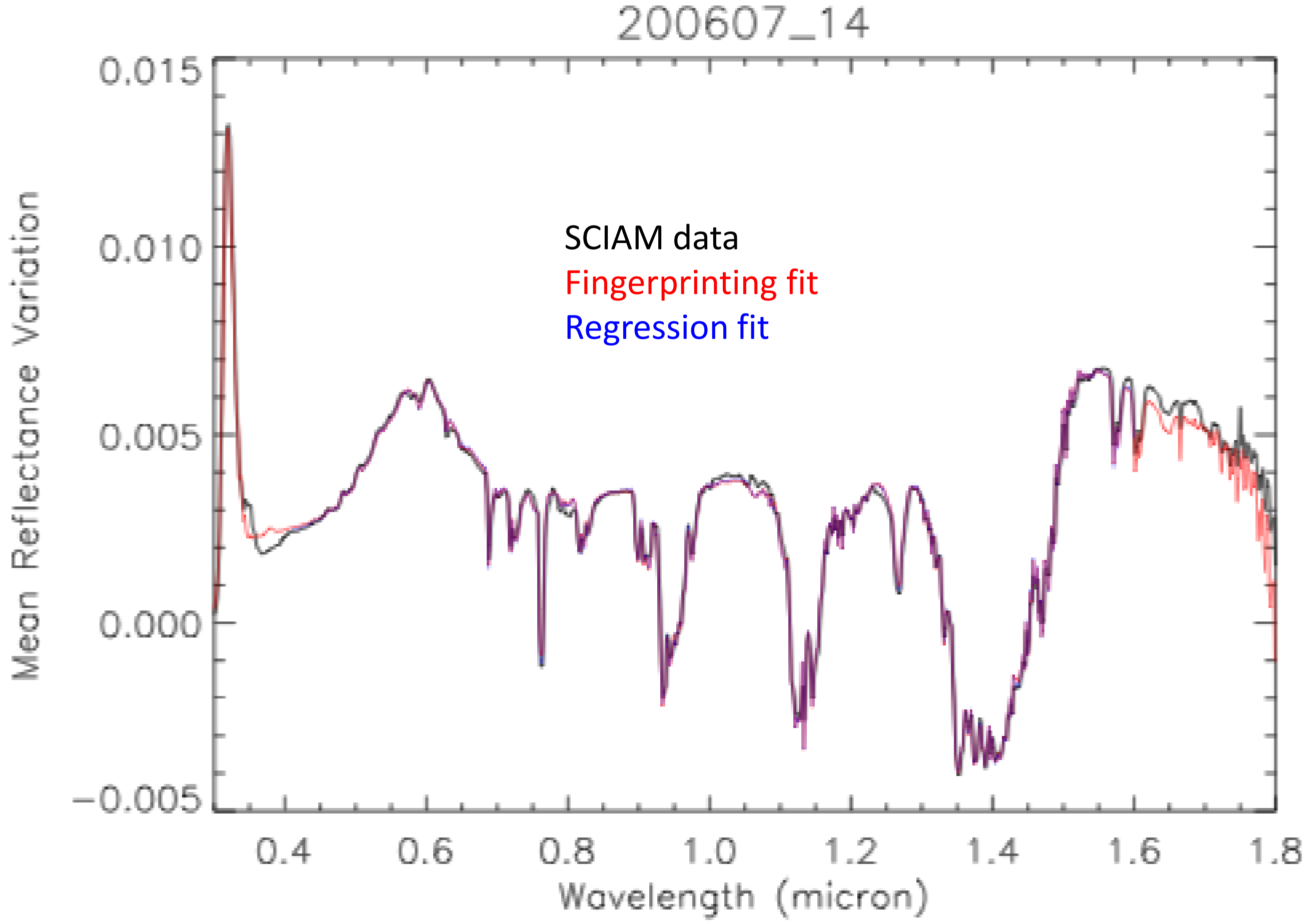
The monthly anomaly is the reflectance difference from the average of the same months across all years.



CERES shortwave reflectance
Spectral-integrated SCIAM

The CERES nadir SW reflectance anomaly is also well correlated with the spectrally-integrated SCIAM nadir reflectance!

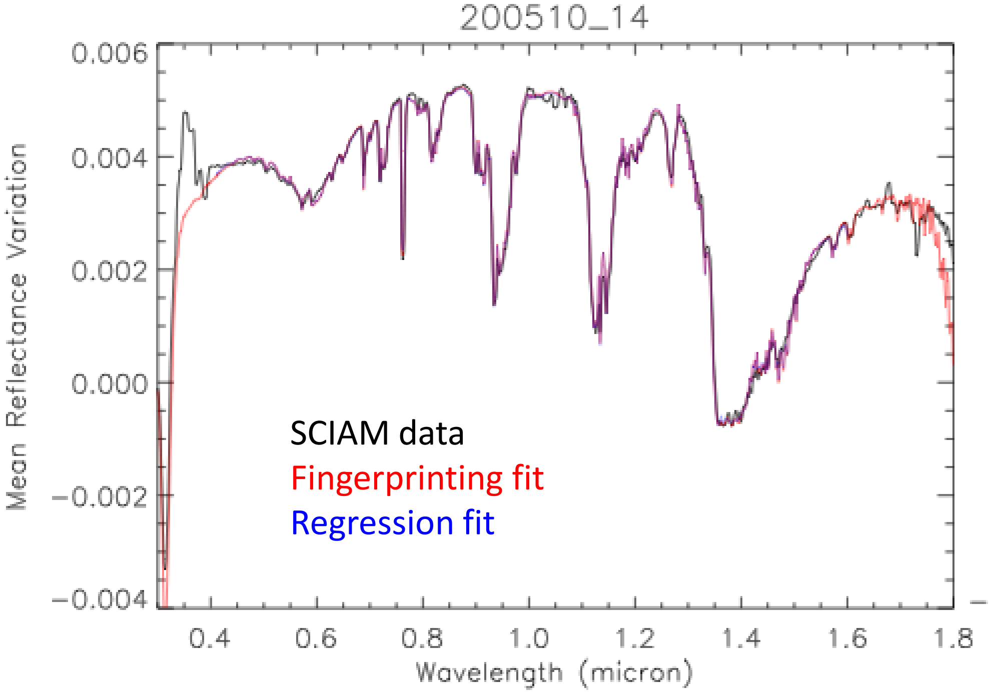
Both spectral and broadband reflectances from the two independent platforms are correlated.
Therefore, data from CERES/MODIS and SCIAM can be used for fingerprinting test!

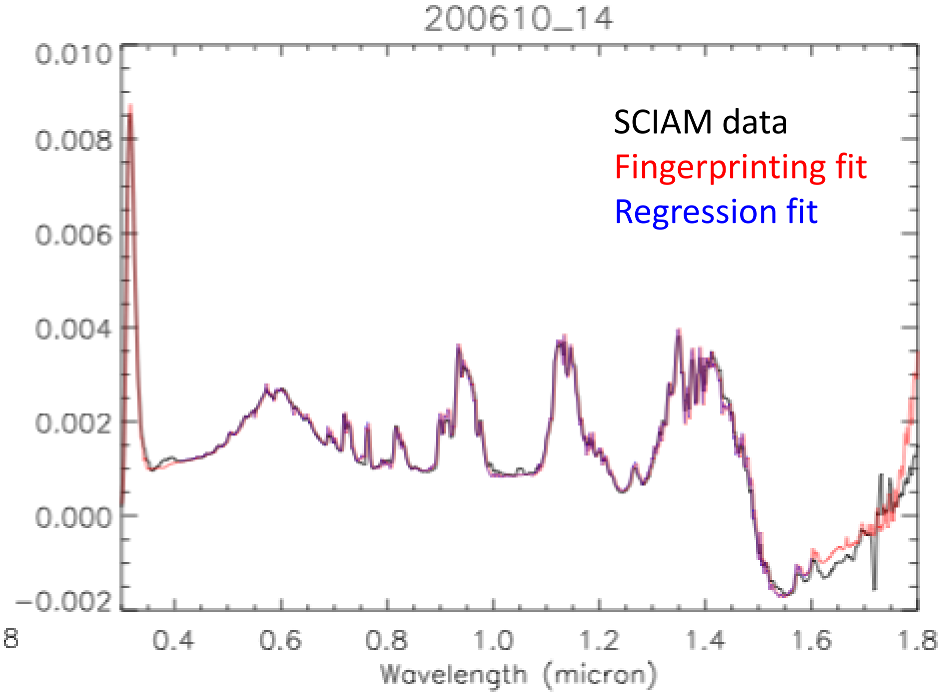


An example of fingerprinting over SCIAM reflectance.

Corresponding Mean Parameter Variation

	PW(cm)	AOD	O_3(du)	τ_i	τ_w	f_i(%)	f_w	h_i(km)	h_w	De(μm)	Re
MODIS:	-0.030	-0.003	-25.4	0.04	0.31	-2.20	3.01	-0.04	-0.05	-0.66	-0.16
Invers.:	-0.005	-0.008	-24.7	0.52	0.17	-2.44	2.44	-0.12	-0.07	-1.12	-0.20
Regres.:	-0.004	-0.004	-25.3	0.60	0.19	-2.55	2.41	-0.05	-0.06	-1.49	-0.23





MODIS
Fingerprinting
Linear-regression

Corresponding Mean Parameter Variation

PW	AOD	O_3	τ_i	τ_w	f_i	f_w	h_i	h_w	De	Re
0.03	-0.003	8.9	-0.10	0.08	0.69	0.59	-0.14	-0.01	0.38	0.20
0.04	-0.013	10.3	-0.54	-0.01	1.63	1.59	-0.03	-0.18	0.58	0.29
0.03	-0.017	10.4	-0.51	-0.06	1.57	2.01	-0.10	-0.17	0.65	0.32

PW	AOD	O_3	τ_i	τ_w	f_i	f_w	h_i	h_w	De	Re
-0.01	0.001	-15.8	0.10	-0.06	0.86	-1.10	0.20	0.04	-0.31	-0.21
-0.03	0.007	-17.0	0.08	0.23	0.63	-3.19	0.18	0.05	-0.37	-0.06
-0.03	0.005	-17.0	0.11	0.17	0.56	-2.75	0.15	0.06	-0.36	-0.02

Initial test of fingerprinting on SCIAM data indicates:

- **Numerical solution can be achieved but not unique.**
- **Solutions are right mathematically, but may not be correct in physics.**

The are several possible sources for the problem in solution:

1. **Uncertainty in the observation spectrum.**
2. **Uncertainty in the kernels.**
3. **Non-linearity issue.**
4. **Error/bias in MODIS clouds and atmospheric properties.**
5. **Inadequate information in the data.**
6. **… …**

Each of the error sources needs to be examined to solve the problem.

Conclusion

- ✓ **Using CERES/MODIS/GEOS observational data, we have created a set of solar spectral radiative kernels, pertinent to the mean reflectance and climate parameter variations over large spatial/temporal domains.**
- ✓ **These kernels provide us a simple way to separate/decompose the radiative response to various dependent parameters and to test fingerprinting techniques for CLARREO.**
- ✓ **The interannual variability of spectral reflectance based on the kernels is consistent with satellite observations (SCIAMCHAY).**
- ✓ **The good correlation between CERES/MODIS and SCIAM measured radiances and the consistency of mean reflectance anomalies between model and observations indicate that the kernel approach is appropriate for fingerprinting test on SCIAM and CERES/MODIS data for CLARREO.**
- ✓ **The next work is to examine the fingerprinting over real data and figure out and solve problems existed, so that it can be used to evaluate the ability of CLARREO to detect various climate changes and feedbacks.**

Acknowledgement:

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